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AFGL MAGNETOMETER NETWORK -
A PROGRAM OVERVIEW

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A summary report of the AFGL Magnetometer Network; its data collection procedures and the data processing sequence.

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AFGL MAGNETOMETER NETWORK

A Program Overview

The goal of this task is to use the AFGL Magnetometer Network data base to improve the Air Force's ability to specify and predict geomagnetic activity. This information is very useful in the studying of propagation of electro-magnetic waves and messages in the atmosphere. Initial efforts are aimed at generating an easily accessible data base for 1-2 years of data. Subsequent work will use the data in spectral and maximum entropy modelling.

Projected users of this data and analysis include Headquarters of Air Weather Service, AFSATCOM, and SAC.

INTRODUCTION

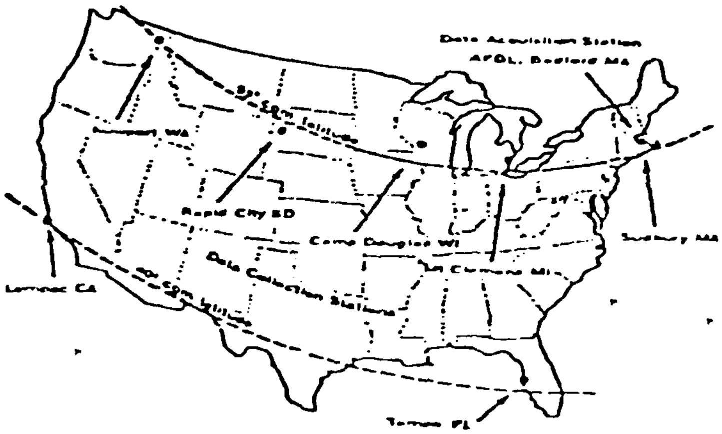
Space affects operational systems because it is a dynamic environment with daily and seasonal variations and with naturally occurring disturbances. A complete understanding of naturally occurring disturbances in the magnetosphere and the ionosphere requires an understanding of the solar contribution to such disturbances. The Air Force is concerned with the degrading effects on its communications and surveillance systems which result from interaction of those systems with a dynamic space environment. However, the occurrence of the magnetic storms or proton showers which cause these disturbances cannot be predicted without a knowledge of the solar activity which causes them.

During periods of high solar activity, a greatly enhanced charged particle population propagates from the sun through interplanetary medium. The solar energetic particles emitted from the sun on interplanetary magnetic field lines leading from the sun to the vicinity of the earth will travel through the earth's magnetosphere and impinge on the polar ionosphere. Solar particle events have a deleterious effect not only on polar communication systems but also on satellite sensors that are irradiated by solar particle fluxes.

AEROSPACE MAGNETIC MONITORING

The ability to specify magnetic activity levels in real time and to predict such activity hours in advance is urgently needed to support various Air Force agencies, including AFSATCOM, SAC, NORAD AND AFGWC. Other users would include SAMSO, ARPA and the various groups engaged in fuel and mineral surveys. A program for specification and prediction requires a system for

the collection of magnetic activity data, its transmission to a central station and the means for near real-time operation on the data. This is being done by the AFGL magnetic monitoring network.



Geographical locations of the stations in the AFGL Magnetometer Network.

Severe magnetospheric disturbances, called magnetosphere storms, produce a variety of adverse effects on operational military systems. The effects result from severe departures from the normal ionospheric and magnetospheric conditions upon which systems such as military communications depend for operation. The objectives of the AFGL Magnetometer Network program include the development of methods to predict magnetospheric storms in order to lessen their impact on military operational capability and the provision of real time data to operational military systems which require a knowledge of magnetospheric conditions for optimum performance.

A magnetospheric storm produces a number of phenomena; its manifestation as a disturbance of the geomagnetic field is called a magnetic storm. The AFGL program chooses the magnetic field as the parameter to be studied because of its direct dependence on the basic processes producing the disturbance and the relative ease with which it may be measured by ground

magnetometers. The practical approach chosen is to measure magnetic-field disturbances at a number of selected locations in the United States with magnetometers which cover an appropriate range of amplitude and frequency and to transmit the resulting data in real time to a central location. The data obtained are measurements of the vector magnetic field at intervals of one second and measurements of the vector time derivative of the field for fluctuations with periods between one and 1000 seconds.

Each instrumented data-collection station (DCS) operates continuously and automatically, unattended except for routine maintenance. Five stations are located approximately along the line of 55°N corrected geomagnetic latitude, and two additional stations lie along the line of 40°N corrected geomagnetic latitude. Data from each station are returned in real time on commercial voice-grade communication circuits to a single data-acquisition station (DAS) located at the Air Force Geophysics Laboratory at Hanscom Air Force Base, Massachusetts. The DAS performs real time processing, reduction, and display of the data and stores processed data in a permanent file for subsequent analysis. All facilities involved are dedicated to the program, so essentially uninterrupted operation over an extended time period is possible.

The important features of the magnetometer network are (a) the ordered array of stations, (b) the measurement of both the vector field and its time derivative at a rapid sampling rate by identical instruments producing directly comparable data, (c) the transmission of these data in real time to AFGL, (d) the automatic real time processing.

All data words are 11 bits in length, with four parity bits added for error-correction purposes. Thus, a frame of data, as prepared for transmission, consists of 240 15-bit words; these are stored in a matrix constructed of 15 240-bit shift registers. Since one sampling interval

follows the preceding one without pause, while data from each interval need to be stored until the assigned transmission time (between zero and ten seconds later), two identical matrices are used in alternation, each being filled in one ten-second interval and storing/transmitting in the next. The output is a serial stream of 3600 bits (240 words of 15 bits each) clocked out at a rate of 4800 bits/sec; the duration of the bit stream is therefore 750 ms.

In addition to the redundant coding obtained by using four parity bits, a technique of interleaving bits from all the words is used to reduce the effect of a noise burst lasting longer than the duration of one bit. The first bit of each word in sequence is transmitted, then the second bit of each word, and so on until the frame is complete. Bursts of errors are thus spread out to cause no more than one bit error per word (which is fully correctable) unless a burst persists for longer than 50 ms. Errors in the data from line noise are entirely negligible in practice.

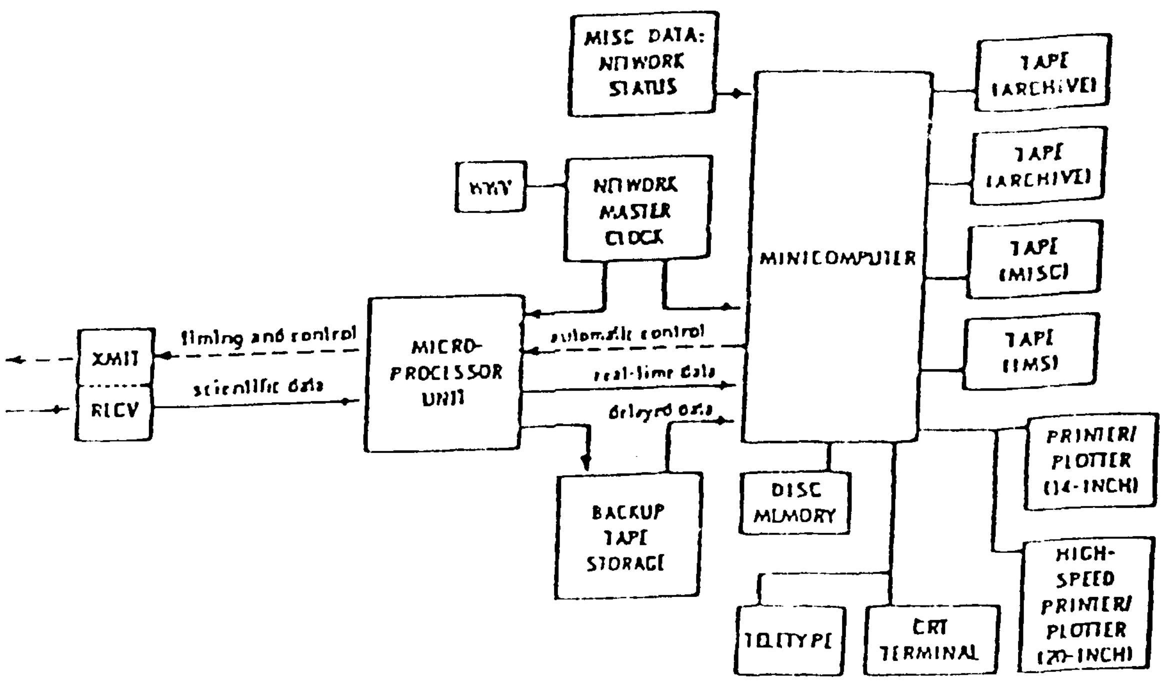
THE COMMUNICATION LINK

The data-acquisition station at AFGL is linked to the data-collection stations by a voice-grade communications network leased from Western Union. The network is full-duplex (i.e. affording simultaneous two-way communication, an outlink and an inlink). It consists of nine segments laid out to form a tree, as shown with AFGL at the base and a DCS at the end of each branch. An outbound signal, therefore, can be sent simultaneously to all of the DCS's, but they must respond in turn. At each hub the first branch with traffic seizes the line and holds it until the transmission is completed.

DATA CONTROL

The functions of the DAS may be grouped in two areas: network control, discussed in this section, and data reception and processing. A schematic representation of the DAS is shown. Ten stations may be accommodated by the communications system. The inlink is used for data return, time shared by all of the DCS's, each of which transmits a frame of digitized data in a programmed sequence. Each DCS responds according to instructions contained in the network-control signal, which synchronizes the taking of data samples by the scientific instruments and the transmission of these data at the proper time. Signal propagation delays are precisely compensated so that sampling times at all stations are simultaneous to within several milliseconds. The details of sampling, storing, and transmitting follow a stored microprocessor program of the DCS.

REPRESENTATION OF DAS



Until the past year, programs which used the data needed to incorporate a means of checking and editing the raw data. This proved to be a very difficult and time consuming activity.

Bedford Research Associates has written a series of computer routines which successfully unpack this very complex data base. Now, for the first time, AFGL scientists have access to processed data with relative eash (with contractor support) and meaningful investigations are now beginning. The project is at a critical phase. Any interruption of support or change in personnel would cause substantial delays for AFGL scientists. While the system is well documented, it is also one that will require many months of time and effort before someone else could be at a stage to even think about using the programs.

This processing capability will be used to generate basic user tapes. These tapes, containing edited data, processed data, will be arranged in compressed blocks covering one minute intervals. The basic user tapes will be made available to the scientific community.

REALTIME DATA

The network minicomputer has the capability of doing some data reduction in real (or near-real) time and automatically providing the results to users via an appropriate communication link. The first such system is under construction; it will provide special 15-minute alerts and 90-minute magnetometer ranges from all stations to the Air Weather Service (AWS) at the Offutt AFB near Omaha, NB, via an existing teletype network. In this system, the minicomputer delivers data every 15 minutes to a fully automated microprocessor-based responder, which constructs formatted messages and transmits them to the AWS computer. It is expected that a realtime detection of sudden commencements and impulses will also be incorporated into this system.

DATA ACCESSING ROUTINE

Since a large data base is being created, a standard routine was envisaged to access any point of the data. This would eliminate any redundant efforts needed to access separate parts of the data in separate analyses. However, detailed consideration was necessary to provide a subroutine which would be easily usable in applications.

The data are read from file MSDATA by functions MGREAD (MSINN, ID, IDATA, NDATA, NSTA). MSINN is the earliest acceptable time in milliseconds since 1970. If positive, the next satisfactory data set is provided. If MSINN is -1, the last data set which was extracted is reused. If a millisecond count is set negative, then only that number of milliseconds or the closest time after that specified is acceptable. If only a particular station is wanted, the negative of the station number is entered in NSTA: positive values are not checked.

The data set is specified by MSINN and possibly NSTA. ID indicates which data are to be extracted from the set.

Of the two decimal digits of ID, the first specifies the type of data, the second subdivides the type. The values 34 and 14 give the vector values of the magnetic field each second and the change in the magnetic field each .2 seconds.

The general requirements defining the main program were flexibility in use, the possibility of expansion and modification and the capability to be used in either batch mode of interactively.

Flexibilities can be obtained through use of the modular structure; each input card specifies a modeule to be executed. This allows modules to be added or modified individually and puts the ordering of modular operations

under control of the input deck. For ease in interactive use and in batch, the input is free form with a keyword being a mnemonic in the operation to be done. Interactive use restricts the size of the allowed program requiring an overlay structure. The main overlay was defined to be small as possible with a higher overlay to interpret the keyword cards and control the main overlay. This allows the other overlays to be treated as modules. The separate overlays act as individual programs except that (1) certain data can be passed between them or saved and reused and (2) they can link each other without requiring another keyword card.

The data is packed into 12 bit quantities, which will be called slots to avoid conceptual problems with 16 and/or 12 bit words. The slots are grouped into sets; the sets in turn are grouped into records.

The data stored are signed integers in 2's compliment form. A slot may contain a single 11-bit integer, sign and a 10-bit magnitude, plus a flag in the low order bit, which is set if the data is suspect. The initial slots in a set, which contain information pertinent to accessing the data, are 12-bit signed integers; i.e., they do not have a flag as the low order bit. However, a string of data may be compressed into an initial value, a string of deltas (the increment from the present value to the next), and the final value. The compression results from the restriction of the deltas to 6,4,3,2, or 1/bit quantities which are packed into the slots giving packing factors of 2,3,4,6 and 12. The shortened deltas are packed from low order to high which is opposite many conventions. The first delta is inaccurate. To reconstruct the data the deltas must be used in reverse order to produce the data from the next to the last value to the second. In the case of a value remaining constant, no deltas are stored and only one value is stored.

Some slots may contain strings of one-bit flags. In this case the packing is from high order to low.

The first three slots of a data set gives the type of data set, the subtype of data set, and the total number of slots comprising the data set.

A data set has two different formats depending on whether packing was used. The fourth word is set to slots containing the information needed to access the data in the two cases. Brackets, [], indicate data which might be packed. Vector data is given in three arrays: all x-data first, then y, then z. X is north, y is east, and z is down.

Since the records have a maximum length of 2560 slots and the sets of slots have a variable length, a data type of -1 terminates the records. There may be slots filled with garbage after the -1 data type but no data should follow until the next record.

The tape ends with a double end of file, a single end of file, or the physical end of the tape. Since some tapes have been restarted, an end of file may be followed by subsequent data.

In addition to the transmission errors which are detected and either corrected or flagged, errors of various types evidence themselves in the time parameter; among these are: erroneous time, data apparently out of chronological sequence, and subsequent data overwriting the start of a data tape.

PROGRAM STRUCTURE

The program was designed for an overlay structure to save space. The main overlay was designed as simply as possible; its sole function is to call higher overlays upon command and pass data. Significant data is passed via commons as are the commands controlling the calling of overlays.

A few generally useful subroutines are included which are used by several overlays. One results of this organization is that general data read to control one keyword may be available for others even when different overlays are used.

The program was constructed and checked under a system which kept a record of all modifications.

Overlay (1,0)---Control

Overlay (1,0) controls the program. Keyword cards are read in and acted upon. For ease in use these are free field cards modelled after the CDC job control cards, except that numeric fields may be either integer or real. Keywords which change parameters or do simple tasks are acted upon in this overlay. Thos needing magnetogram data request the main overlay to call in the appropriate overlays before returning control to this overlay. In this way, the modular structure of the entire program is maintained; control of the sequence of operations is given to the person running the program through the keyword cards.

Overlay (2,0)---Data Base Access

In many ways this overlay does the main task of the program: a data tape is read and a compact data file is created. The data tape, MGDATA, is read by MGREAD as described in section 2.1.1. The data is checked for bad spots while being unpacked and bad data is replaced by 99990. or 99999. (This could be changed through common /MGREADC/). The data times returned are checked if the data is to be used. Times showing jumps greater than 15 seconds are stored until either the time discrepancy resolves itself or the error storage area is filled. In the former case, the times of the saved data is corrected before the data is used; in the latter, the new time is considered correct. Time reversals due to long sections of bad data impede

the use of following data. For this reason MGDATA is not normally rewound before use so that the tape may be positioned externally from the reading routine.

Once the data has been unpacked and checked for problems, especially time discrepancies, and it is from one of the stations and time interval desired, the data is stored by routine STODTA in the buffer IBUF. When this buffer is full, the routine AVGOUT is called to pack the data into the buffer IØB. The data is packed by averaging controlled by two main parameters: NMSAVG and MSDAVG. NMSAVG is the number of milliseconds to be averaged over. MSDAVG is the displacement from one average to the next. NTAVG AND NTDAVG are the number of time points in the average and in the displacement assuming MSPT milliseconds per time point. Depending on the relative values of these parameters, the averages may overlap producing smoothing or they may be widely separated for sampling. Averaging over one sample results in direct use of the data. Data which was flagged by MGREAD is not used and averages with no data are flagged by AVGFLG, set to 65536. Times having no data are flagged by FFLAG, also set to 65536. Data not needed for further averaging is flushed from the buffer and the remaining data repositioned.

When the output buffer is filled, subroutine IØBUT is called to output the data as a record of file AVGEN and to adjust the buffer parameters to allow more data to be placed in it.

Overlay (3,0)---Plotting

This overlay extracts data from AVGEN and organizes it for plotting. The plotting request can be for any length of time, and for any number of stations. To allow for this flexibility, the routine may break a requested time period into several plots. Each plot is limited to MNP points, currently equal to 720. This may result in sampling the points rather than use all

of them; in this routine, sampling rather than averaging is done.

This overlay and the next can be used interactively to examine sections of the data in as much detail as desired.

Overlay (4,0)---Specialized Storage

This overlay transfers data between the standard file and a random access main storage file. When data is transferred from AVGEN, the two files do not have to agree in their parameters controlling the spacing of data points. Data from AVGEN, falling with the time interval and from the desired stations will be transferred to the position in MSFILE whose time is the closest. When a new AVGEN file is created, its time parameters are derived from thos of MSFILE. To make the file AVGEN more compact, only data from the specified stations are used and only times having at least one valid piece of data are used.